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# An Evolutionary Approach for Global Production Network Optimisation

G. Schuh<sup>a</sup>, T. Potente<sup>a</sup>, D. Kupke<sup>a</sup>, R. Varandani<sup>a,\*</sup>, C. Hausberg<sup>a</sup><sup>a</sup>Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Steinbachstraße 19, Aachen 52074, Germany\* Corresponding author. Tel.: +49-241-8027424; fax: +49-241-8022293. E-mail address: [r.varandani@wzl.rwth-aachen.de](mailto:r.varandani@wzl.rwth-aachen.de)

## Abstract

The continuous growth of production networks has led to an increasing number of planning objects which need to be integrated into the network planning scope. Dealing with the increasing complexity of this multi-dimensional decision making problem means identifying the planning objects and defining clear optimisation criteria. The developed application consists of two main components. One is the optimiser which avails itself of a genetic algorithm and the second is the data viewer which enables a user-friendly and interactive assessment of the results. The application was successfully employed within the manufacturing industry.

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## 1. Introduction

In the past decades multinational companies have formed global production networks in order to leverage cost potentials or capture new markets with growth potential. Many of the production sites in these networks have been set up or acquired empowered by individual decisions. The continuous growth of production networks has led to an increasing number of planning objects which need to be integrated into the planning scope.[1][2] Dealing with the increasing complexity of this multi-dimensional decision making problem means identifying the planning objects and defining clear optimisation criteria. A number of applications and digital tools with different objectives have reinforced a heterogeneous and unfocused character of the planning process.[3] However, a targeted optimisation and evaluation process are required to assess and redesign a companies' global production network. Thus, the demand for an interactive computing application taking into account the main planning objects, production volume and production resources, is apparent.

In order to cope with the challenges in global production network optimisation the Laboratory for

Machine Tools and Production Engineering (WZL) has developed a software tool named "OptiWo" that uses modern optimising methods based on operations research to design and evaluate production networks.

## 2. Motivation

Within the scope of this paper two central problems are described. The first issue may be outlined by the complexity and size of the solution space when designing a global production network taking into account all the possible production sites, products, process steps and production resources.[4][5] Consider, for example, a network with ten possible production sites, 200 products to be allocated, each to be produced using one of three alternative process chains of each four to eight steps and with each process step to be performed on one of two or three production resources in one of the ten production sites leads to a solution space of  $10^{4500}$ . Comparing this to the number of atoms in our universe, approximately  $10^{80}$ , gives a mere feeling of the tremendous task of finding the optimal configuration.

The second issue is enlarged by the lack of time available to decision-makers to comprehend the vast

information required to make judgments about changes in the global production structures sometimes worth many million euros. Rather often managers have only few minutes to understand the available information and take major decisions.[6]

The twofold problem described in 2.1 leads to two key challenges faced by globally active companies today. The first challenge lies in tackling the huge solution space, taking into account the relevant constraints for a company.[7] The collection of the required product, process and resource data provides the basis for this but, moreover, a method is required which allows companies to process these data and to find an optimal solution. The optimal solution is mostly driven by cost minimisation but should also account for the customers' delivery time requirements.

Furthermore, a user-friendly or rather manager-friendly solution module is needed to facilitate the processing of information and in turn propel an easy and transparent decision-making process in companies.[8]

### 3. State of the art

As described, the two major challenges in the optimisation of production networks lie in tackling the huge solution space and preparing the results in a manager-friendly way. There have been many different approaches for the evaluation and optimisation of production networks.[9] Several of these approaches can only be used for evaluation of defined scenarios without an automated reduction of design possibilities. Furthermore, the graphical output is often limited to huge spread sheets or simple bar charts.

#### 3.1. Existing approaches for production network design

Cohen and Lee [10] developed a stochastic optimisation supply chain model, which incorporates a series of stochastic sub models (material control, production, stockpile inventory, and distribution). These sub models are then optimised individually, and are linked together by a heuristic optimisation rule. Later on Goetschalckx, Vidal and Dogan [11] included transport information within their model. A standard solver was used to find optimal solutions. Similarly, Sabri and Beamon [12] engaged themselves in developing a planning model for production, delivery and demand uncertainty. The production processes and resources were, however, not taken into regard in these approaches. Merchiers [13] developed an extensive evaluation model to evaluate production network scenarios. This model can only be used for the evaluation of fixed-defined scenarios. An automated optimisation of the production network does not take place. Justus [14] developed a modular simulation

model. The evaluation is with respect to total landed costs and total landed time. The scenarios need to be developed manually and permanently programmed into the tool. Finally, the recent work of Lanza and Ude [15] is to be acknowledged especially because it evaluates ramp-up behaviour and offers a detailed simulation using a simulation software.

#### 3.2. Existing commercial IT tools for production network design

Furthermore, many large scale digital tools and software solutions have been designed in order to evaluate different production networks. Some key examples of IT tools for production network design and their functionalities are listed below:[16]

- SAP APO (Optimisation of existing plant of a company)
- Axxom - Orion-PI® Value Network Optimization (Green field scenarios and optimisation of network structure)
- PowerChain Network Designer (Multiple criteria, investment planning support)
- ILOG LogicNet Plus XE (Optimisation of supplier and logistics network)
- SCM Strategic Network Design (Calculation of production and transport costs)
- Oracle – Strategic Network Optimisation Workbench (Constraint-based cost optimised network design)

Most of these tools are stand-alone tools requiring an immense data input. Others, for example the SAP APO software, can access a data base provided by any number of SAP modules existing in an enterprise. However, the cost of each module and the required hardware often exceeds the budget calculated for planning tools, especially in small and medium enterprises (SMEs). SMEs therefore cannot afford large scale solutions.

#### 3.3. Genetic algorithms

Genetic algorithms belong to the group of evolutionary algorithms used to solve problems which cannot be solved by analytical means. Evolutionary algorithms generate different solutions through repeated mutation and selection. They belong to the heuristic optimisation methods and are used to solve problems with tremendous solution spaces and complexity in an efficient manner.[17] Genetic algorithms use the principle of evolution in order to generate solutions by the use of a computer. Holland and Goldberg [18][19] established genetic algorithms striving for convergence in the search for the optimal solution of a problem. Genetic algorithms have been applied in many industries in order to define an optimal design. An example can be found in the telecommunications field, where genetic

algorithms are used to find the optimal network infrastructure with its number, type and position of components and cable paths.[20] Within the scope of global production network design genetic algorithms have been employed in the field of operations research.[21] Many of the developed models focus on the logistics systems required to run global networks rather than focusing on strategic decisions regarding a companies' global production structures.

#### 4. Optimisation approach

Optiwo is a software tool developed by the WZL. It consists of two components: the "optimiser" on the one hand, which uses a genetic algorithm to deliver a cost-optimal Global Footprint within a defined solution space and a data viewer on the other hand. The viewer has been specifically developed under the aspect of usability. Its interactive user interface and visualisation technique ensure a fast apprehension of complex data.

##### 4.1. Optimiser

The optimiser uses a two-step approach: it first creates a Global Footprint and then calculates the cost of that footprint. In order to be able to create a footprint, the user has to feed the software with data regarding, for example existing products, processes, resources and production sites (Fig. 1). This data defines the solution space in which the software will search for cost optima.

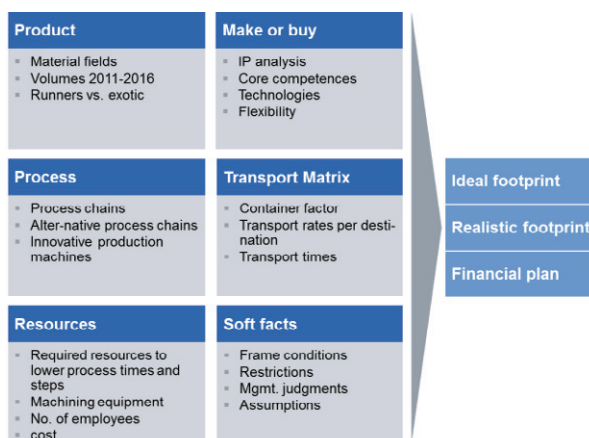


Fig. 1. Structure of the evaluation model

Generally, the user is not limited regarding the data complexity – he can model both existing and future production networks, with alterations regarding products, process chains and production sites. The user can model an infinite amount of products, including demand volume and location. In the case of modeling a

hypothetical or future scenario a make-or-buy decision can be taken into account.

For example, an IP (intellectual property) analysis can lead to the conclusion that a particular process should be executed internally and not be performed outside the home country. This provides a restriction for the further design of the global production network. For each modeled product at least one process chain that represents the production process of that specific product has to be defined. If desired, alternative process chains can be defined for the same product. This option also allows including new technologies for the production of a certain product which do not exist yet but are most likely to be used in the near future. The software will then also consider the split of the production of a product on different process chains.

Significant characteristics of each process chain are the first and the last process step. The first step defines the sourcing of raw material, whereas the last step defines the demand/ supply location. The latter sets the necessary transport routes within the production network. By the definition of an additional fictitious process step the general idle time within each process chain can be considered. Only by taking the idle time into account a comparative evaluation of the transportation time regarding the maximum delivery time is possible. Furthermore, it is possible to define different transportation process steps between the opening and ending transport steps. All process steps in between two transportation processes take place at one production site. In order to enable the tool to evaluate each of them financially, a container factor for each product has to be established. The container factor specifies the amount of a specific product that can be transported in one container taking a product mix in the container into account.

Starting with the definition of the process chains, the user then has to allocate one or more resources to each process step. This takes into account that a product will be usually produced on its dedicated resource, but also could be produced on a different resource that does not fit perfectly but would still be adequate, e.g. on a larger machine. The differences that result regarding the processing time can of course be defined within the tool. This option allows a focused analysis of the advantages and disadvantages of deploying highly automated versus universal or even "exotic" machines.

Regarding the standard setting of the software tool, the defined resources can be allocated to all production sites. Nonetheless, the user can include restrictions of course, stating for each resource at which production sites it can be installed and where it must not. This applies to machines that must not be moved from their original site due to technical or financial reasons for example. The option to include a restriction where no

resource from a certain site must be moved (or alternatively defining only one site as location for all machines concerned) of course implicates that this specific site must not be shut down, thus allowing to incorporate according strategic decisions made by the management.

After having fed the software tool with all data necessary, the optimiser starts to allocate the products to different sites. This is done by first assigning the total demand volume to possible process chains. Within those process chains, each process step is then assigned a specific resource which is in turn allocated to a specific site that is available for that resource. However, the software tool only indicates the allocation of a resource to a site, if that resource does not exist there yet or if the existing resource's capacity is not sufficient for the production of the particular product. This allocation process is being repeated by the software tool until all products have been allocated.

Finally, the amount and the type of resources that have been allocated to each site determine the cost of a certain Global Footprint. This requires that the resource-specific cost is not dependent of the resource's location which can be assumed with sufficient certainty. Nonetheless, each site is assigned a basic site cost, but this does not affect the resource's cost. The total footprint cost can therefore be split into fixed and variable cost, see figure 2.

Costs for the following are taken into account: direct and indirect labour, logistics, assets, energy, depreciation, maintenance, consumables as well as allocations.

A significant cost factor is the cost of labour. It is evident that they depend on the amount of resources employed at each site – the more resources there are the more employees are necessary to operate the machines. In order to quantify the direct labour cost, the amount of operators for each resource has to be defined. Due to multiple machine work the factor can of course be less than one, too. Another input necessary for the calculation is the site specific labour cost. Last but not least, the labour cost is multiplied with a productivity factor that can be defined not only for each site but also for each resource separately. The calculation of indirect labour cost as well as intra logistics within each site is carried out identically.

Another significant figure whose importance will increase in the future is the energy cost. Those are defined and calculated within the software tool based on the cost of running one resource for one hour.

Naturally each resource's acquisition cost has to be stated as well. Together with the amortization period they influence the footprint cost, just like the maintenance cost and cost for consumable goods (e.g. tools) that are also entered per running hour for each

resource. In the end the implicit interest cost is also included.

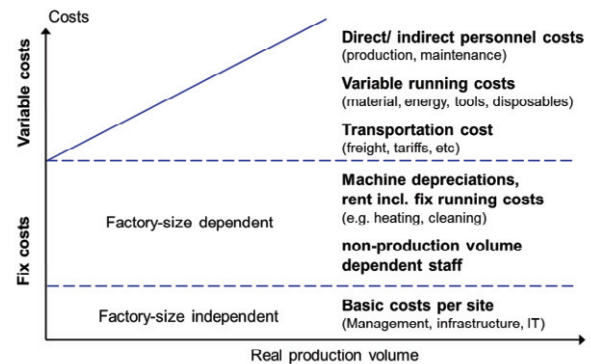


Fig. 2. Structure of the cost model

Last but not least, it is necessary to state the floor space for each resource. For sake of simplicity, the required amount of space for walkways and storage should be included proportionally. Those figures enable the calculation of the total space necessary for a certain site. In combination with lease and rental charges that are defined per site and square meter the software calculates the footprint's share of real estate costs.

Other cost factors include custom duties, transportation costs and material costs.

Those types of costs arise within the different transportation processes. The amount of material costs for example depends on the data of every first transport process which can vary regarding both the product as well as the location.

#### 4.2. Data viewer

Upon completion of the optimisation, the software tool creates a output file that can be loaded and visualised in the data viewer. The data viewer is a web application based on Java, JavaScript and HTML.

The first visualisation level shows the footprint's total cost, variable and fixed costs, cost per production site, transportation costs and customs duties.

Furthermore, there are several options to visualise the results. Using a resource and product sheet which show the results in a classic data table, the resource sheet states the amount of resources per location as well as the average utilization of each resource. The product sheet states how many process steps a certain product has to undergo at each location as well as the total throughput time of each product for the chosen Global Footprint configuration. Furthermore, each table contains an overview of cost per location.

Besides the visualisation using the data table, it is also possible to depict the distribution of the product



(volumes) for all locations on a world map, as shown in figure 3. This map also allows visualising the transport volumes and routes between all locations.

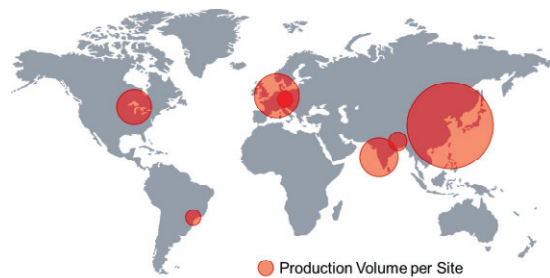


Fig. 3. Visualisation of the distribution of volumes

Another possibility is the tree map which visualises the size of the production sites, the amount of resources within as well as their utilization, see figure 4. In the picture, the size of the rectangles represents the amount of resources of a certain type, whereas the colour of the rectangles represents the average utilization of those resources. Additionally, the rectangles representing the resources are aggregated into a larger rectangle whose size represents the size of the production size.

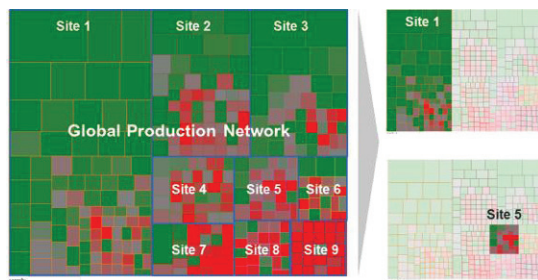


Fig. 4. Visualisation of the number of machines and their utilization

A user interface input mask allows an easy-to-use and quick highlighting of different production sites and resource types – the rectangles that match the search criteria are highlighted in a different colour.

Besides the visualisation of data, the data viewer also allows two other analysis options.

Firstly, it allows carrying out sensitivity analyses: slider allow for an individual variation of the cost influencing factors labour cost, productivity, monetary exchange rates and material costs. This can be done for the entire footprint or for specific production sites. Changes of the Global Footprint cost are calculated and visualised on the fly.

Secondly, a manual configurator allows for the manual alteration of data of the entire production network model. Changes can be made for example regarding resources and their allocation to specific sites. This enables the user to change throughput times or

transportation cost and cost of customs duties without a new optimisation run. The changes in the total footprint cost as well as production site-specific cost are being visualised immediately.

#### 4.3. Integration within the Virtual Factory Framework (VFF)

The tool described is finally integrated into the Virtual Factory Framework (VFF) which is a large scale European Union project. The tool is one module of an entire framework of tools scattered around the factory lifecycle. A common data structure based on the utilization of ontologies throughout all modules is used to enable the exchange of information such as resource, process or product data, hence, facilitating the planning process for companies along the factory lifecycle.

The designed tool will be employed as part of a validation scenario within the automobile and consumer goods industry. As a stand-alone solution it has already been validated within the manufacturing industry as described in the next chapter.

### 5. Validation within the manufacturing industry

In cooperation with an industrial partner a project has been carried out, where the Optiwo tool has been used to create an optimal Global Footprint in the year 2016. The growth of a globally operating engineering and plant manufacturer has led to a complex production network. Therefore, the established structures should be examined critically as well as the future design of the network should be developed more systematically in future.

Key questions were

- Where should the client produce which product?
- How close to the corresponding markets have the products to be produced?
- Which influences do different customs duties, transport costs, exchange rates and costs for raw material have on the total cost of the Global Footprint?
- Are additional production sites economically viable?
- Is the consolidation of European production sites necessary?

#### 5.1. Project approach

The project has been divided into three phases. The first phase of the project consisted of filling the software tool with the necessary input data. For that purpose, the data had to be collected, analyzed and structured. This leads to a profound model of the production network including all value streams. Phase one ended with the software tool's optimisation process that calculated an

“Ideal Global Footprint” where the solution space was still large.

The second phase consisted of the implementation of several restrictions to restrict the solution space. One of those restrictions was the requirement of the client to ensure a shorter delivery time for his customers. The restrictions included also the requirement to not turn a production site redundant, as described in the example in chapter 4.2. However, the most important restriction was the financial limit for investments that are needed for the reconfiguration of the production network. To meet this requirement many machines get fixed to their actual sites to avoid the movement and the transportation cost. In this manner several real Footprints were created.

In the third phase, a full financial plan for the next five years was derived for the most realistic scenarios taking the limited investments per year into account.

## 5.2. Project results

With the help of the developed scenarios for all questions in section 5.1 clear recommendations could be derived. Due to the stated delivery time expectations was suggested to relocate the bulk of the production volume that has not a critical delivery time to China. In addition, the consolidation of the European sites was recommended. The opening of new sites was even in case of increasing production volumes considered as non-economic.

A byproduct of the project was the data transparency, which was created in the course of data provision. Among other things, for the first time maximum delivery time expectations were defined for all products, as well as for the first time tariffs, transportation costs and material costs have been brought together so comprehensively.

## 6. Summary

The software tool Optiwo is an innovative method that enables companies to optimise their production network with the use of mathematic optimisation algorithms. Especially small and medium sized companies with global production networks can profit from the tool.

Regarding the project approach, a suitable solution space has to be determined – the software’s large amount of possibilities which correlates with the quality of the optimal solution has to be reduced in order to balance the effort that is necessary to use the tool with the company’s available resources. It has to be kept in mind that every additional product for example can create a more realistic picture of the production network, but it also require more time to define all its demands, process chains including resources, process times and

restrictions up to pallet factors for the transportation. The solution space therefore has to be set individually for each project.

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